CRYOGENIC DISTRIBUTION SYSTEM FOR THE PROPOSED CORNELL ERL MAIN LINAC*

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Abstract

The proposed Cornell ERL main linac requires a total cooling power of 7.3kW at 1.8K, 6.8kW at 5K and 144kW at 80K. This is distributed over approximately 65 cryomodules, each containing 6 rf cavities and associated input couplers and higher order mode absorbers; situated in two underground tunnels connected by a 180 degree turnaround at the outer end. While the total heat load is comparable to that for each of the 8 individual LHC cryoplants, the very high ratio of dynamic heat load to static heat load, combined with the high power density at various sites produces interesting challenges for the cryogen distribution system. A schematic view of the design choices selected, some of which are different from existing large cryogenic systems, together with the basis for these decisions, is presented in this paper.

REFRIGERATION PLANT

The cryogenics plant will be housed in a building at the surface level, about 25 m above the two sections of the tunnel in which the half-linacs, containing a combined total of 64 cryomodules, are located (see Fig. 1).

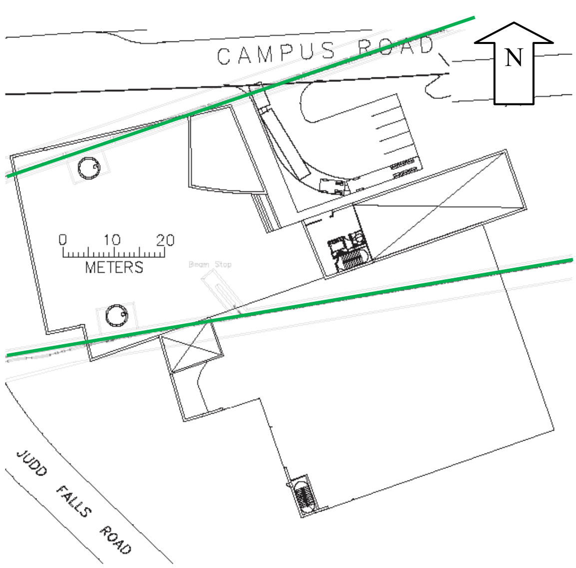

Figure 1: View of refrigeration plant and roads. Tunnel is indicated by green lines under building. Cryogenic feed is through circular shafts from the building to the tunnel 25m below.

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Cold boxes for the refrigeration will be in the western room most nearly above the closest approach of the two tunnels, compressors which may provide more vibrations are located in the southeastern room. There will be two refrigerators working in parallel to provide coolant streams at 1.8K, 5K, and 40K, and these coolant streams and the returning gas streams will flow through vertical vacuum-insulated transfer lines to the two half-linacs below. Interconnections at the cold box level will allow for some flexibility in relative supply of coolants to the two segments of linac. The total refrigeration capacity is intended to be 7.3KW at 1.8K (delivered as subcooled liquid), 6.8KW at 5K (delivered as gas slightly above the critical point and returned as 6.5K gas), and 144KW at 40K (delivered as 20 bar gas, and returned as gas at 80K), which allows for 50% more than the design heat loads at each level. It is intended that some variation in the relative heat loads at each stage of refrigeration can be tolerated, as particularly at the 1.8K level and the 40K level the dynamic heat load is very much larger than the static heat load, and can vary greatly depending on the mode in which the accelerator is being operated. In part because of space limitations at the intended site, it is planned to have the majority of the helium inventory (ca. 25,000 liters) maintained in the form of liquid, with an additional existing medium pressure gas storage tank capable of holding an additional 5,000 liquid liter equivalent. It will be necessary to have internal bypassing of various levels of heat exchange within the refrigerator in order to have efficient operation during the cooldown process for the linac. It may be necessary to have an auxiliary small liquefier (100W at 4.2K) to maintain the inventory in liquid form during extended shutdown periods.

DISTRIBUTION IN THE TUNNEL

Within the underground tunnels, each half linac is comprised of 32 cryomodules individually assembled and tested, but welded together in the tunnel and sharing a common insulation vacuum. There will, however, be a vacuum break between each cryomodule string and the vertical transfer line connecting to the refrigerator cold boxes. Each cryomodule will contain six 7-cell SRF cavities operating at 1.8K, each with an individual input coupler, seven higher-order mode (HOM) absorbers operating at 80K, and one set of 1.8K superconducting magnets for focusing and orbit correction. The common insulation vacuum space for the group of 32 cryomodules will house delivery and return piping for the entire string

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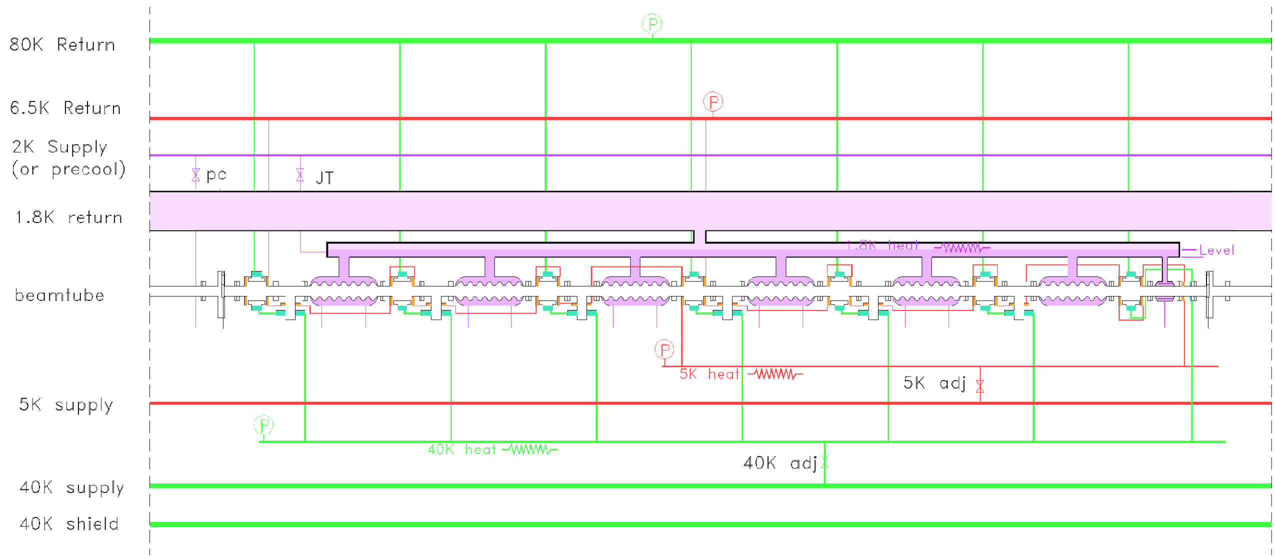

Figure 2: Cartoon view of cryogen distribution within a single cryomodule.

of cryomodules, but there will be individual valving to regulate and adjust the amount of cryogens delivered at each temperature stage at the level of the individual cryomodule. Each thermal stage presents its own special demands on the cooling and distribution requirements, and they will be discussed individually. First, however, it is useful to consider the cartoon view of the plumbing arrangements within a single cryomodule as shown in Fig. 2.

1.8K Distribution System

The large diameter (280 mm) helium gas return pipe (HGRP) plays both a structural role in supporting and positioning the cavities, HOM absorbers and couplers within the cryomodule, but also provides the low impedance needed for the large mass flow rate of gas (up to 180 g/s) at 12 torr without excessive pressure drop over a distance of 350 meters. Connected to the HGRP at a single point is a 100 mm 2-phase helium manifold which has a 75mm connection to each of the helium vessels surrounding the superconducting niobium radio frequency (RF) cavities. The purpose of this large 2-phase tube is to allow adequate surface area for evaporation and a sufficiently large cross-section for gas flow through it to the HGRP to avoid generation of waves on the liquid surface which could result in pressure fluctuations affecting frequency tuning of the cavities. It is desirable to have only one connection between the 2-phase tube and the HGRP because there is enough pressure drop in the HGRP over the 10m length of a single cryomodule at the end of the string nearest the cryoplant so that a significant portion of the gas flow would flow through the smaller 2-phase pipe rather than through the intended HGRP, thus resulting in wave generation. The size of the 75mm pipe connecting between each cavity helium vessel and the 2-phase line is dictated by a maximum superfluid helium heat transport of about 1 W/cm^2 at this temperature.

Subcooled helium at 1.8K is supplied through a 50 mm pipe which runs through the entire length of the half linac in normal operation of the accelerator. In each cryomodule it is admitted to the 2-phase line through an electro-pneumatic metering valve which is adjusted to keep the liquid level (measured with a superconducting level detector) constant at about 1/3 the height of this line. It is important that the temperature stability should be very high, preferably at the mK level within a given cryomodule, so that there are not pressure fluctuations causing the resonant frequency of the cavities to shift. However, there will be a noticeable gradient of pressure, and hence temperature, along the total length of a half linac.

The dynamic heat load for the 1.8K system with the full field gradient of 16MV/m in the cavities which is expected in normal operation is nearly 10 times the static heat load when the RF power is turned off. While the microwave power being coupled into the cavities can be switched on or off in seconds, the refrigeration plant will require a time scale on the order of hours to re-equilibrate to the changed heat load, and would certainly exhibit serious transient response problems if the load were changed in a step-function fashion. To avoid this problem, electrical heaters will be mounted on the 2-phase line, and used to ramp the 1.8K power demands smoothly between active and standby states. We do not wish to have the heaters on for very extended periods of standby operation with the refrigeration plant running at full load, because the wall-plug power for the refrigeration plant is in the MW range, and it is desirable to be able to operate with as little average power over an annual cycle as is compatible with experimental time.

During cooldown of the accelerator from room temperature, it is important to be able to inject cold gas from the refrigeration plant into the 1.8K system in a uniform way which limits thermal gradients in the system.

In this mode, a separate valve from the 1.8K distribution pipe will be used to meter gas into opposite ends of each cavity helium vessel through small pre-cool lines, while the normal-operations valve is kept closed off. This is particularly important in the temperature range near 9K, the region where the niobium cavities first become superconducting, where large temperature gradients across the cavity may result in degraded performance.

5K-6.5K Distribution System

The 5K coolant supply will be distributed at a pressure somewhat above the critical point for liquid helium (around 3 bar), where helium gas conveniently has an increased heat capacity. The main supply and return lines again run through the entire length of a half-linac, and are 50 mm diameter lines. Because the heat loads at many of the thermal intercept points are rather large and we can not accept temperature gradients between coolant stream and thermal anchor point of more than a few tenths of a kelvin without degrading the superconductivity properties of adjacent niobium cavities, it is not practical to use copper straps to connect between a distribution pipe and the anchor point, but rather we need to use convective transport of helium gas. We have enough total mass flow so that the pressure drop along the supply lines for a half-linac is large compared to the pressure drop which would occur in the small tube passing from supply to return and brazed to a thermal intercept with an appropriate amount of flow, so we cannot passively just put hundreds of small tubes in parallel and expect uniform cooling. A good compromise appears to be to have a regulation valve at each cryomodule which feeds a subdistribution line, then put several of the individual lines in series to make the pressure drop from supply to return rather larger. Two such groupings per cryomodule appears sensible in modeling efforts. The choice of temperature rise between supply and return is a compromise between reducing the mass flow of gas through the refrigeration system to improve refrigeration efficiency and keeping the outlet temperature low enough to not degrade superconducting properties of the cavities. There is a significant component of dynamic heat load for the 5K system, but much less severe than for either the 1.8K or 40K systems.

40K-80K Distribution System

The heat loads are much higher in this part of the cooling scheme, and the gas densities are lower, despite operating at a supply pressure of 20 bar (chosen for efficient refrigerator operation). Copper strapping is again not a satisfactory method of taking out the heat. Also, there is a dramatic difference in heat load depending on beam current (HOM power going as beam current squared). Again we have chosen to use 50 mm diameter piping for the supply and return lines, but in this case if we just used two lines running the entire length of the cryostat, pressure differences between the supply and return pipes would vary dramatically along the length of the linac (the high pressure end of the supply line would be opposite the low pressure end of the return), with the difference being amplified as the heat load increases. By adding a third delivery line (which will be an aluminum extrusion integrated into the 40K thermal radiation shield), it is possible to have the high pressure end of the supply tubing matched up with the high pressure end of the return tubing for the cross-flow links. Again, one actuator controlled regulation valve per cryomodule to an intermediate manifold will be needed to make it possible to balance the flows at an adequate level along the linac.

The static heat load coming in to the thermal radiation shield is sufficiently low so that the temperature of the 40K supply gas is raised only a few degrees along the length of a half linac. The principal loads for which we need the convective transport of the helium gas to provide cooling are a thermal intercept on the input couplers for each cavity, a thermal intercept on the magnet leads, and the center of each of the HOM absorbers, which in normal operation will represent almost all of the heat load. By placing in series either an input coupler thermal intercept or the magnet lead intercepts with each HOM load, we can have seven flow channels for each cryomodule which are very similar in total heat load. By putting the lower demand thermal intercepts on the supply side of the series connection, we benefit by reducing the load on the 5K intercepts immediately adjacent to them, but have very little impact on the upper temperature reached by the HOM absorbers. The exact temperature at which the HOM loads equilibrate is not very important, although it has a second-order impact on the heat load that is experienced at the 5K stage. Since there will be variation in the amount of higher mode generation on a cavity-by-cavity basis, there will likely be variations by tens of kelvin from one load to another. Our main concern is to ensure that temperatures do not rise above 120K on any given load, just to ensure that the loads do not experience an unnecessary amount of thermal expansion cycling. Initial choice of metering valve settings for each cryomodule will be done by adjusting differential pressures between the local supply manifold and return pressure to be similar along the length of the tunnel. Fine tuning under load may be done by minimizing excursions of maximum HOM temperature for the half linac.

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